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FINDINGS FROM MAJOR STUDIES OF FATIGUE[1/]

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INTRODUCTION

Under compulsion of the present urgency to implement the President's promise to make the United States the arsenal for the democracies there is a tendency to demand a relaxation of restrictions on hours of labor and to speed up all industrial processes. The pressure is the more insistent with growing realization of the importance of the time factor in the successful prosecution of the war effort and the lack of skilled workers due to operation of the draft, lack of an apprentice system in industry, and loss of skill by workers unemployed for long periods during the depression. With "total" war such as it is today the probabilities are that everyone will be required to exert greater effort (in many instances in activities to which they are unaccustomed) for longer periods than ever before has been necessary. The question arises, "What will be the aftereffects as

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well as the immediate effects on health, safety, and efficiency?" A review of the literature leaves the impression that this question has not been answered completely, especially as regards the ultimate effects.

Mechanization, speeding up of industrial processes, mass production, and the small industrial concerns present many problems to industrial medicine. Does the tendency to expect the worker to produce at full speed all the time he is on the job decrease the effectiveness of the shorter working hours and cause undue fatigue, loss of efficiency, and increased accident proneness? The answer is important as this condition is likely to be intensified by the exigencies of the present emergency. According to Viteles (1)[3/],

> The increased tension under such conditions of work appears to offset the savings in muscular force made possible by the machine. The tension, the speed, the subjection to specialization of work and a rhythm uncontrolled by the individual promote fatigue, characterized by a "decrease in the power to work, a decrease in pleasure taken in work, and a decrease in the enjoyment of the hours spent away from work."

The crowding of workers in temporary structures without proper provision for comfort and health may add greatly to the general fatigue factors already present in many industrial establishments. In 1932 Lockhart (2) stated that the production and maintenance of a healthy, satisfied industrial population is the most urgent necessity, involving problems so serious as to constitute a national task too great economically to be relegated to industrial concerns. If this was true in 1932, it must be doubly so today.

In a recent book, Outlines of Industrial Medical Practice, Collier (3) states:

> If strong personal or social incentives are brought into operation, human beings can attain high speeds of work and high intensities of concentration over considerable periods. But it was made abundantly clear during the last war that concentrated efforts of this kind deplete the physiological and psychological reserves and finally result in the onset of chronic fatigue and illness.

3/ Figures in parentheses refer to items in the bibliography.

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Perhaps the surprising success of the German "Blitzkrieg" may be explained partly by the depletion of the physiological and psychological reserves of the European democracies by the World War of 1914-18. Although Germany suffered much from the blockade during that period, she did not experience the horrors of invasion and the destruction of her physical resources as did France and Belgium on land and England at sea. Also, she had the strong incentives of revenge and the impelling impulse of a defeated people (obsessed with an inferiority complex) to attain a position of superiority in the world and thereby regain her self-respect as well as acquire extensive physical resources.

FATIGUE AND HEALTH

Although data available show the connection between fatigue and loss of working efficiency and increased accident occurrence, there is little actual medical proof that long fatiguing periods of work affect the health or working capacity adversely.

According to Vernon (4), investigation of sickness of about 20 percent of the English workers in the iron and steel trade during the pre-World War years 1913-14 and the period 1915-18 revealed that days of sickness in wartime averaged 31 percent less than in peacetime, the older men showing a greater reduction than the younger men. He considers this diminution of sickness to be more remarkable when one remembered that a large proportion of the younger and more vigorous men (about a fifth of the whole body of workers) joined the Service at one time or another. His explanation is that during the war the men probably were determined to stick to their work, even if they were on the borderline of sickness, while they reduced their periods of convalescence considerably. In this connection it is interesting to note a recent statement by the London correspondent of the American Medical Association (5) that health in English factories is as good as before the war, the Government's attention to health in factories having been well-rewarded. The provision of canteens in and out of factories, the reduction of long hours in the first year of the war, and the development of medical services have kept the workers in good condition.

Definition of Fatigue

Webster defines fatigue as "weariness from labor or exertion; exhaustion of strength; loss of power due to continued work but removable by rest." The Health of Munitions Workers Committee of the British Association on the Question of Fatigue from the Economic Standpoint (6) defined fatigue as "the sum of the results of activity which show themselves in diminished capacity for doing work." Spaeth (7) said "Normally fatigue

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may be considered a condition of lowered capacity for work, resulting directly from the accumulation of the products of activity and varying with the duration, rate, and intensity of the performance, and the initial strength or capacity of the physical system involved." Viteles (1) gave the following as the popular and scientific conception of industrial fatigue: (a) An overt manifestation in the form of reduced output on the task, known as work decrement; (b) a physiological state involving changes in organic functions and the production of chemical products of fatigue; (c) a feeling of fatigue or tiredness. Collier (3) states that fatigue is a general term applied to a variety of reactions of workers to their industrial environment. These reactions manifest certain common characteristics which are objective or physical and subjective or psychological in nature. The essential physical manifestation of fatigue is diminished capacity for continuing the fatiguing task and a diminished capacity following the long-sustained performance of that task. In its extreme manifestations it is indistinguishable from exhaustion and is accompanied by complete inability to continue to perform the task. The essential psychological manifestation of fatigue is an increasing disinclination to continue working and is accomplanied by certain more or less typical "feeling states." The fatigued worker begins to lose interest in his work and then experiences active disinterest or boredom. If the same occupation is continued, increasing annoyance and irritation may result - the stage at which industrial fatigue tends to produce industrial unrest. Embden (8) considered death and fatigue as comparable processes and fatigue as incipient death, which is reversible.

The causes of fatigue may be physical or psychological. It is apparent from the literature that psychological and environmental factors are far more important causes of fatigue than physiological factors. Bock and Dill (9) mention two types of fatigue - one originating entirely within the central nervous system, the other arising partly in the nervous system and partly within the active muscles. The former is of common occurrence, whereas the latter occurs infrequently. Industrial fatigue usually is of the first type.

Studies on the physiological and environmental factors in fatigue, reported recently by the Committee on Work and Industry of the National Research Council (10), indicate clearly the importance to health and efficiency of such factors as temperature, altitude, relations with management and fellow workers, and home and community life, especially conditions causing emotional strain.

As the whole story of fatigue is long and complicated the discussion in this paper will be confined to some of the objective or physical phases of the subject.

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Physical Manifestations of Fatigue

Collier (3) emphasizes that fatigue is a "transition state" between health and disease and that many so-called physical illnesses are aggravated, if not caused, by precedent states of fatigue. As an example, he mentions that artificially fatigued animals are rendered more susceptible to infection by pneumococcus.

The connection between fatigue and health is indicated by experience in England (11) with women munitions workers during the World War. Medical examinations of large numbers of women munitions workers in 1916 and 1917 showed that a third of the workers examined evidenced "some fatigue or ill health," while 7 percent showed "marked fatigue or ill health." These figures apply to the women who were actually working, but many of them became so sick that they had to give up war work altogether. In each 3-month period more than a quarter of the women gave up work, largely because of ill health, and had to be replaced. It was not possible to trace their later history, but the mortality records of the Registrar-General showed an increase in deaths from tuberculosis. In 1918 the deaths from this disease among young women 15 to 24 years of age was half again as great as in the years 1911 to 1914. It was considered that the increase in deaths among young women was due largely to the war work under war conditions. The rise in tuberculosis cases was particularly noticeable in the large industrial cities where there was a marked influx of war workers. The effect on the death rate of women from respiratory tuberculosis is shown in the following table by Vernon (4):

Age of Women	Death rate per 1,000 in -			Percent rise between 1911-14 and 1918
	1911-14	1918	1920	
15-19.....	1.01	1.51	1.07	49
20-24.....	1.12	1.69	1.28	51
25-34.....	1.28	1.57	1.13	23
35-44.....	1.32	1.48	1.03	12
45-54.....	1.11	1.19	.85	7
55-64.....	.90	.90	.66	0
65-75.....	.66	.62	.53	-6

In 1936 Ascher (12), a former public-health officer and director of the Social Hygiene Research Board, Frankfort on Main, Germany, published an interesting report on the influence of work on health as a result of studies he made during the depression in Germany following 1929. By comparing morbidity and mortality statistics for the more favorable

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conditions of life covering periods of full-time occupation with those for the less-favorable conditions of decreased working hours and unemployment he claimed to have shown, for the first time in the history of social hygiene, the isolated influence of working hours on the sickness and death of workers, the influence being manifest in the decline during the depression of sickness and the death rate, especially in cases of tuberculosis. (This agrees with the statement regarding increased tuberculosis in women workers in British munition plants.) The sickness rate among employees of an engineering works in Frankfort on Main, in which a 26-hour week had been introduced, in 1932 and 1933 was 32 percent of that in 1928, while public-health insurance dropped only to 71 percent, although the latter showed a lower sickness rate in 1928 (4.08 compared to 7.7). Ascher states that these statistics correspond with statistics for the United States for 1929 to 1933.

According to figures compiled by the National Tuberculosis Association (13) in 1936 the tuberculosis mortality rate for agricultural workers was 47 per 100,000, while that for unskilled industrial workers was 185.

According to Vernon (4), the excess of tuberculosis among young women is not limited to war years. Data relating to mortality in London show that in 1921 the death rate from tuberculosis among single women 15 to 30 years of age was substantially higher than in 1911, probably owing to their employment in industrial occupations. Compared with 1921-25, there was a substantial rise in 1926-30 in the incidence of tuberculosis among women 15 to 25 years of age, although among younger and older women there was a fall. Men between the ages of 15 and 25 were also affected to some extent, their case rate showing much less improvement than younger and older men.

According to Collier (3), recognized "industrial diseases" do not arise in occupations that demand severe physical exercise, but cardiovascular diseases occur with undue frequency according to some observers. The fact that athletes apparently do not experience demonstrable aftereffects from their athletic efforts does not mean necessarily that continued heavy muscular work does not predispose a man to certain types of circulatory disease. Whereas athletes abandon strenuous competitive games at a comparatively early age, industrial workers continue their work until incapacitated. In this regard Collier (3) states:

> An examination of the mortality returns in the Registrar-General's Analysis of Mortality according to Occupation shows that excess mortality from diseases of the heart and blood vessels is observed in two large groups of occupations. The

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first group consists essentially of heavy manual laborers and the second of certain light occupations in which dietary and social influences are in operation. The list of occupations show how frequently occupations that are classed as "II. Heavy manual labor" experience excessive mortality from diseases of the heart. The second group in which the anginal diseases are prevalent are managers of food businesses, wholesale proprietors and managers, commercial travelers, civil-service executives, bankers, actors, teachers, innkeepers and barmen, clerks and typists. As the Registrar-General observes, angina and acute endocarditis are diseases of affluence. The only other considerable exceptions to the generalization that heart diseases are characteristic of the heavy industries is the group of costers and newspaper sellers, but this unskilled group is largely recruited from workers in the heavy occupations or those who have found the heavy occupations too strenuous after 45 years of age.

Other recognized industrial risks of the heavy manual occupations are accident, hernia, traumatic rheumatism and varicocele, flat-foot and postural deformities.

A study of death rates by occupation, prepared by Whitney (13) of the National Tuberculosis Association in 1936, revealed that the rate for males from all causes (corrected for variation in age) was 623 per 100,000 for agriculture workers, 775 for clerical workers, 829 for skilled industrial workers, 1,009 for semiskilled industrial workers, and 1,448 for unskilled labor.

Winslow (13) compares mortality rates according to groups as follows:

Perhaps the most illuminating comparison may be obtained by ignoring the agricultural workers, with their very low rates, and contrasting the clerical group as a whole with the combined industrial group, including skilled, semiskilled, and unskilled workers. The mortality rates of the industrial workers as a whole for all causes of death exceed those of the clerical workers by 320 per 100,000, which means that in every 100,000 industrial workers there occur (at corresponding ages) 320 more deaths than among 100,000 clerical workers. Of this excess of 320 deaths per 100,000, 20 deaths only are due to accidents of all kinds, 38 are due to pneumonia, and 54 to pulmonary tuberculosis. Thus, an excess of accidents accounts for only one-sixteenth of the

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total excess death rate of the industrial workers, while an excess of pneumonia is nearly twice as important and an excess of tuberculosis nearly three times as important.

It is not, of course, for a moment intended to imply that this total excess of mortality among industrial workers is entirely due to hazards of industry. Social and economic conditions, racial habits, individual personal handicaps, physical, mental, and emotional, all play a part. The direct influence of industrial conditions is, however, relatively, probably just as great in pneumonia and in tuberculosis as in accidents.

This comparison indicates the importance of health to industry and to the country at large, especially during a time when every bit of power and every ounce of energy are needed to produce for national defense. If illness causes 15 to 20 times as much absenteeism and about 7 times as much loss of time from work as accidents (14), the seriousness of the health problem, whether due to industry or not, is indicated by the loss from industrial accidents of approximately 1,500,000,000 man-hours of production each year in the United States. In spite of the decidedly greater loss due to ill health,4/ virtually nothing has been done to correct conditions compared with what has been and is being done to prevent accidents. Considering accidents before health would seem to be putting the cart before the horse, as a worker in good physical condition is less likely to have an accident than one who is physically unfit. Viteles (1) found average lost-time accidents among men suffering from physical defects to be three times as high as for men without such defects. A close relationship was observed between the frequency with which men working in the metal department of a motor-car factory reported sick at the ambulance room and the frequency with which they suffered accidents (4).

Types of Industrial Physical Fatigue

Physical fatigue may be temporary, subacute, or chronic. Temporary fatigue is a normal feeling of tiredness that passes away after a short rest and allows resumption of the original work without decrease in efficiency. Beginners and unskilled workers tire sooner than the more experienced and skilled workers. As proficiency increases time required to produce fatigue increases.

4/ The Gallup poll estimated that the time lost from war or war-connected industries because of illness in December could have built 2 heavy cruisers, 448 medium bombers, or 3,200 light tanks - a total of 23,000,000 man-days. (Heiser, V., A Prescription for Production: Survey Graphic, vol. 31, 1942, pp. 108-112.)

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Subacute fatigue may result from continued activity at the same intensity until energy reserves are depleted. This is a short-term condition but if allowed to continue unchecked ultimately will develop into a chronic condition.

Chronic fatigue is the final stage of a series of events of which overwork is the first stage. It is also the beginning of a condition that may end in disabling illness.

Fatigue may be local or general. Local fatigue affects particularly the muscles that have been employed most actively. General fatigue affects the whole body and frequently results from conditions of work, such as excessive hours, curtailed periods of rest, and insanitary, uncomfortable, or hazardous surroundings. According to Sanders (15), fatigue results from muscular or nervous effort which, although local at first, becomes general when sustained until the local functions no longer can cope with it. He groups the different types of industrial fatigue as due to (a) work for which the worker is temperamentally unsuited, (b) unnecessary motions by the worker, and (c) unsympathetic surroundings. The first two types are generated within; the third is due to outside causes.

Simonson and Enzer (16) stated recently that hard muscular work or work under high temperature produces fatigue of peripheral physiological functions, such as metabolism, circulation, and respiration. In easy muscular work, such as office, shop, laboratory, and many industrial operations (assembling, textile, and food factories), fatigue originates exclusively in the central nervous system.

Physiological Basis of Fatigue

If the body is to perform maximum work with minimum effort, complete coordination of muscular movements with the activities of the respiratory and circulatory systems is essential. Exaggerated response by these systems involves useless expenditure of energy. A deficient response interferes with the controlling influence of the nervous system, cripples the energy of the skeletal muscles, and renders exercise ineffective or impossible. Muscular exercise thus presents the following problems (17): (a) Changes in the skeletal muscles which affect the transformation of energy constituting muscular movement; (b) adjustments elsewhere in the body to provide the muscles with the oxygen and foodstuffs required for this purpose; and (c) the means by which these are interwoven and bound together to produce the fabric of muscular exercise.

Reaction of muscle to stimulus. - Repeated excitation of muscle by stimuli of equal strength at equal intervals results in certain reactions

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that in general are consistent (18) as follows: The first three or four contractions decrease slightly in extent (this phenomenon is frequently absent.) After the first slight fall the contractions increase in extent with great regularity and often are surprisingly numerous. This activity has been called the "staircase" (German "Treppe"); it indicates that in the beginning activity is beneficial to the muscle in that its irritability gradually increases due to an initial increase resulting from chemical products formed during contraction. After the period of the "Treppe" contractions diminish steadily in height until the muscle fails to respond to stimulus. This progressive loss in irritability is called fatigue.

When a muscle is stimulated a chemical reaction occurs, in consequence of which energy is liberated in the form of heat and free energy. The free energy is stored in the muscle in a form that the muscle can utilize later for its contractions. The efficiency of different muscles or of the same muscle in the same animal may vary under different conditions of nutrition. The efficiency of human muscles in work is determined by subtracting the heat produced during rest from that during work, the difference giving the new energy developed in the muscles. The average results of experiments of this kind indicate an efficiency of about 21 percent, which compares favorably with 15 to 25 percent, that for a steam engine. Experiments indicate that there is an optimum load for each muscle with which the greatest proportion of work can be obtained.

Experiments on persons reveal that if the interval of rest between the contractions and the weight of the load lifted are kept constant the contractions decrease in extent with fatigue until with the strongest voluntary effort contraction of the muscles is insufficient to lift the weight. Experiments also show (18), however, that (a) when enough of an interval is allowed between contractions fatigue is not apparent; (b) after complete fatigue with a given load a very long interval is necessary for the muscle to recover completely and to give a second record as extensive as the first; (c) after complete fatigue efforts to contract the muscle still further greatly prolong the period of complete recovery - a fact that demonstrates the injurious effect of straining a fatigued muscle; (d) the power of a muscle to do work is diminished by conditions that depress the general nutritive state of the body or the local nutrition of the muscle (for example, by loss of sleep, hunger, mental activity, and anemia of the muscle); (e) improved circulation in the muscle increases the power to do work (food has the same effect, especially sugar); (f) the total amount of work that can be obtained from muscle is greater with small than with large loads; and (g) marked activity in one set of muscles will diminish the amount of work that can be obtained from other muscles.

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The sensation of fatigue resulting from continued voluntary contractions probably arises from stimulation of the sensory nerve fibers within muscle and may be regarded as an important regulation to prevent muscular exertion to the point of "straining." Fatigued muscle relaxes more and more until it is completely nonirritable. Howell (18) defined fatigue as more or less complete loss of irritability and contractility due to functional activity. Ranke (19), who was the first to investigate this subject thoroughly believed that chemical changes in muscle during contraction form certain substances that depress or inhibit the power of contraction. In support of this view he found that extracts made from fatigued muscle of one frog caused fatigue when injected into the circulation of another fresh frog. He proved that these fatigue substances consist of the known products of muscular metabolism. Ranke's contentions that the products of muscular activity diminish or suppress the contractility of muscle if allowed to accumulate therein have been confirmed by other observers. These products primarily are lactic and phosphoric acids. Experiments on man (18) indicate that violent exercise lasting for only 1-1/2 minutes may cause a large increase - 29 to 100 mg. per 100 cc. - in the lactic acid of the blood.

Spaeth (7) called attention to the anabolic and catabolic phases of metabolism, which are interrelated in such a way that they tend constantly to balance each other. The work reaction of muscle is gradually limited and regulated by the accumulation of lactic acid, one of its products. If this is removed, the work reaction continues much longer. During and following human muscular activity lactic acid and certain other products of muscular work are removed, in part mechanically, by irrigation of the circulation. The blood likewise deposits sugar in the muscles and thus constantly replenishes the source of high potential energy. It is possible for a muscle to work at such a rate that the removal of acid is exactly as rapid as the deposit of sugar. The muscle is then in the condition of dynamic equilibrium and may continue almost indefinitely.

Collier's (3) theory of fatigue follows:

> The simplest hypothesis by which the various phenomena associated with fatigue can be explained is to suppose that the state of fatigue arises whenever the output of energy exceeds the intake: but "intake" and "output" must be understood in a very general sense. Thus, the deficiency of intake or the excess of output may be either quantitative, in respect of the time factor, or qualitative, in respect of the particular kind of energy output or intake concerned. Time is required to assimilate food and to restore depleted stores of energy; while, if the output of emotional energy at work is high, the proper

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steps must be taken to restore the reserves of that particular kind of energy in the body. If fatigue is regarded as being due to a lack of balance between intake and output in some part of the psyche-soma[5], we must ask from which sources that lack of balance rises. Firstly, it may have its origin in the environment whenever it is of such a kind that a high output of energy is needed in order to preserve the psyche-soma in a "steady state." It is for this reason that a cold shop, a nagging foreman, or unhappy group relations in a workshop are found to be fatiguing by the worker. Secondly, it may arise from excessive output of energy within a given time; fatigue may result from this whenever speeds of work are too high or a very high degree of concentration on the work is demanded. Lastly, fatigue may be caused by a defective intake. To maintain psyche-somatic balance, a period of activity must always be followed by adequate rest.

It is important to stress the time factor in the production of fatigue. The immediate requirements of the individual, for any kind of energy, must be supplied from his accumulated reserves. If these reserves are allowed to become depleted, relatively easy tasks may tire him. It is the depletion of the reserves of energy that cause the chronic industrial fatigue that is one of the most important problems of modern industrial life.

Spaeth (7) stated that the definition of fatigue as "lowered capacity for work" is inadequate, as working capacity may be lowered by conditions other than fatigue; moreover, he claims that fatigue is not invariably indicated by lowered capacity for work as, for example, the phenomenon of "second wind" and the great increase in muscular efficiency under stress of emotional excitement. This increase is due to the action of the sympathetic nervous system on the adrenal glands which causes the release of adrenin into the blood. Adrenin causes the liver to liberate sugar, which is the chief source of potential energy in muscular activity. It also increases muscular efficiency by increasing the rate and force of the heart beat and thereby the flow of blood into the working muscle, sweeping away the products of metabolism. Adrenin also has the power of restoring the irritability of muscle. According to Cannon (20) "What rest will do only after an hour or more, adrenin will do in 5 minutes or less." This increased efficiency, however, is temporary, and the production of adrenin cannot be substituted indefinitely for sleep and normal rest.

Howell (18) doubted that muscles could be injured directly by overwork under normal conditions, as they are protected by the sense of fatigue which

5/ Defined by Collier as "body-mind" unity.

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makes the voluntary use of muscle more and more difficult. Fatigue itself probably develops in the motor end plate and the nerve centers more quickly than in the muscle; this physiological process protects or safeguards the muscle from an extreme condition of fatigue. Although strain usually is not prolonged enough to injure the muscle itself beyond possibility of restoration, occupational neuroses indicate that the nerve centers may be damaged and that other mechanisms, such as the heart and blood vessels, may be injured, particularly if there are abnormalities in structure or function. The sites of fatigue are summarized by Boyd (21) as follows:

> The receptors, neurons, and muscles are the sites of fatigue.
>
> 1. Receptor fatigue is fatigue of the end organs. We may particularly distinguish fatigue of the olfactory, auditory, and optic end organs. Some odors affect the ability to distinguish similar or other odors, which must be considered a manifestation of fatigue. Auditory fatigue only affects the ability to hear sounds in higher register. Optic fatigue is manifested by a reduced visional acuity.
>
> 2. Neuron fatigue occurs centrally, the axon being considered indefatigable. Morphological changes in the nerve cells and nucleus with a chromatolysis are observable, and physiologic changes, as shown by a rise in the threshold value between neurons, are seen in the spinal reflexes.
>
> 3. Muscle fatigue may reside in the end plate or muscle fiber. The end plate may be fatigued while the muscle is still capable of contracting. The muscle contraction varies with constant or variable loads. With a constant load the contractions will finally cease, while with a variable load they will go on indefinitely. The rate at which they contract is as important as the load in the production of fatigue. The fatigued muscle is less irritable to stimulation, but increased stimulation will produce an increase in the height of contraction. The reaction of the muscular protoplasm changes to acid from neutral or alkaline, due to the formation of sarcolactic acid and monopotassium to carbon dioxide. As a consequence lactates and lactic acid may appear in the blood and urine following fatigue. Muscular fatigue is due to the accumulation of these waste products in either the

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muscles or the blood. If in the muscle, their accumulation may be due to the failure of the blood stream to remove them. The massage of a fatigued muscle assists in the removal of the fatigue products by the circulation. Recovery is also hastened by oxygen. The accumulation of fatigue products in the blood affects muscles other than the ones involved in the exercise; thus local fatigue becomes general.

In 1907 Fletcher and Hopkins (22) suggested that normal contraction may be caused by development of lactic acid with free hydrogen ions in the vicinity of colloidal fibrils, as the artificial application of lactic acid to muscle causes contraction, reversible by removal of the acid. They did not know exactly how the formation of lactic acid from some carbohydrate forerunner takes place when an impulse reaches the muscle from the central nervous system; but once formed contraction would be maintained if the acid were not removed by oxygenation which takes place rapidly when oxygen is present, with the formation of carbon dioxide and water.

Dill (23) has called attention to the complex chain of chemical reactions involved in the conversion of the chemical energy of fuels to mechanical energy. One of the earliest reactions involved in muscular contraction is the break-down of phosphocreatine to inorganic phosphate and free creatine. This energy-yielding reaction is believed to be reversed by the formation of lactic acid from a precurser (probably glycogen); and only after this stage is oxygen employed. These first two reactions can supply energy for work far in excess of the rate of oxygen supply. When an oxygen debt (which the body has the capacity for accumulating) is contracted lactic acid escapes from the muscle and appears in the blood, its concentration furnishing an index to the size of the debt. As the concentration of lactic acid depends on the degree of exhaustion, it has been assumed incorrectly that lactic acid is a toxin and that if in some manner its accumulation could be prevented fatigue would not develop. According to Dill (23), a more logical view is that the attainment of high levels of oxygen intake may be favored by the accumulation of lactic acid. It has been proved that the heart prefers lactic acid to glucose as a fuel; and possibly both skeletal muscle and heart muscle are benefited by an increase, within reasonable limits, of lactic acid in their environment. Investigation in the Fatigue Laboratory of Harvard University (23) shows that the ability to accumulate lactic acid in exercise is characteristic of youth. With advancing years the decline in capacity for accumulating lactic acid parallels the decline in capacity for severe work. Dill (23) concludes that the conception of lactic acid as the toxin of fatigue must be abandoned; instead he considers it a substance as physiological as glucose.

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Schneider (24) states that the manner in which muscular contraction is produced is a matter of speculation. Until the part played by phosphocreatine in muscular contraction was discovered most investigators believed that the liberation of lactic and phosphoric acids evoked the contraction. However, it is now known that lactic acid is formed too late to take part in the process of contraction.

Chemical and physical theories have been advanced to explain this process. The chemical theories assume an exothermic reaction; the physical, a release of electrical energy by stimulation. According to the first group of theories some chemical reaction occurs before contraction begins; according to the second all known chemical reactions should occur in the recovery process by which the store of energy is replaced. According to Schneider (24), available evidence does not greatly favor either. The question at issue between the chemical and physical theories could be settled if the time relationship of the chemical break-down of the organic compounds were known accurately. He points out that an adequate theory of muscular contraction should explain the mechanism that produces the shortening of the contractile elements, the nature of the energy that is transformed into chemical work, and the relation of these phenomena to the chemical changes that follow stimulation of the muscle to activity.

Owing to incomplete oxygenation, some of the intermediary products of muscle activity may gain access to the blood stream. After moderate exercise, Hyffel (25) detected lactic acid in the urine and sweat.

In 1920 Scott and Hastings (26) published the results of an investigation to determine a change in the chemical composition of the urine that could be used as an index to fatigue. They found that the severity or arduousness of any particular form of labor could be judged by the ratio of the morning to the afternoon sulfate of the urine, provided enough determinations were made on several individuals. They found also that unconjugated phenols were slightly increased by moderate work and greatly increased by strenuous exercise, suggesting that the excretion of free phenol may be a factor in severe fatigue.

According to Schneider (24), excessive, violent exercise quickly causes a rise of the lactic-acid content of the muscle to the maximum of about 0.28 percent; muscle is incapable of further effort when it contains this amount of free acid. When a fatigued muscle is placed in oxygen the lactic acid will decrease to the resting value, provided enough oxygen has access to the muscle fibers. With a reduction in lactic acid the muscle regains its irritability. In voluntary muscle all oxidation is regarded as recovery oxidation.

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Role of Respiration and Circulation in Fatigue

Role of respiration. - According to Fletcher and Hopkins (22), chemical changes during muscular contractions occur in two stages, the first of which is the formation of lactic acid and the second, its removal. The production of lactic acid which culminates in muscular contraction is a nonoxidative process and can take place in the absence of oxygen, while its subsequent removal is an oxidative process which requires an adequate supply of oxygen.

The rate at which oxygen is consumed by the body during exercise varies almost directly with the amount of external work performed. A similar relationship exists between pulmonary ventilation and consumption of oxygen by the body. When exhaustion approaches at the end of a short period of exercise the increase in ventilation is out of proportion to the consumption of oxygen. This excessive ventilation probably is the result of a decreased supply of oxygen to the tissues, which leads to accumulation of lactic acid, increase of acidity, and decreased saturation of the arterial blood. The amount of oxygen that can pass into the blood is determined by the total ventilation of the lungs, the nature of the oxygen-dissociation curve, and the partial pressure of oxygen in the inspired air. A man's maximum working power is determined not only by the functional capacity of his skeletal muscles but also by the supply of oxygen to the muscles, heart, and brain. The supply of oxygen apparently is the limiting factor. The following data on oxygen consumption and volume of air breathed during moderate exercise are taken from Schneider's (24) summary of a table by Douglas and Haldane:

Exercise	Oxygen consumed, cc. per minute	Air breathed, liters per minute
Rest-standing.....	328	10.4
Walking at the rate of 2 miles an hour	780	18.6
Walking at the rate of 3 miles an hour	1,065	24.8
Walking at the rate of 4 miles an hour	1,595	37.3
Walking at the rate of 5 miles an hour	2,543	60.9

Apparently the experimental study of the control of breathing during physical exertion has not progressed far enough to explain how the respiratory center is stimulated (24). It is evident that the activity of the

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center varies directly with the severity of the work until lactic acid begins to escape into the blood, at which time breathing increases disproportionately. How the many factors, such as carbon dioxide, acid-base balance, body temperature, and higher nervous-center impulses, interact to produce the breathing responses to exercise cannot be described at present.

Bainbridge (17) states that undoubtedly the hydrogen-ion concentration of the blood is one of the means by which oxygen is supplied to the muscles in accordance with their requirements during exercise. Another factor determining the capacity of the muscle cells to utilize oxygen appears to lie in their intrinsic physicochemical properties. The rate at which lactic acid accumulates during exercise in the blood of an untrained subject contrasted with the steady state of the athlete appears to be associated not only with the total intake of oxygen but also with the capacity of the cell to burn the products of catabolism (17). The total oxygen consumed during exercise is roughly proportionate to the mass of active muscles.

A further and more delicate adjustment between the activity of the skeletal muscles and that of the medullary centers is required to maintain adequate blood pressure for the nutritive requirements of the heart and brain, and to make the necessary correlation between the venous inflow and the pulse rate required to sustain the mechanical efficiency of the heart and body as a whole. The controlling influence of the higher centers is manifest at every stage of exercise, although it is seen most clearly at the outset of exercise and during emotional stress; and the ability of a man to make the fullest and most efficient use of his muscles is determined by the accuracy with which this higher coordination is effected. A man's nervous organization is as important as the size of his muscles, and his muscular development is by no means the only criterion of his capacity for muscular exertion.

Role of circulation. - Strenuous physical work or sport may lead to enlargement of the heart. Investigators (8) have found that the size of the heart of an animal reflects the amount of activity characteristic of its mode of life. Rabbits, run long and strenuously, showed hypertrophy of the right heart and signs of acute emphysema. As a result of examination of participants in the German games and of 12 professional 6-day bicycle racers, Herxheimer (8) offered the theory that exercises of strength, speed, or extra effort induce hypertrophy of the skeletal muscle and only to a small extent increase the heart mass, whereas exercises of endurance lead to hypertrophy of the heart, leaving the size of the muscles unchanged. This is a logical application of the principle that a muscle taxed beyond its capacity responds with hypertrophy. Results of other investigators (8), although not as convincing, point in the same direction.

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Physical training reduces the pulse rate, according to most investigators (8). This decrease has been found mostly in those whose hearts also enlarged. At rest the trained or athletic subject has a higher minute volume than the untrained. Apparently a linear relationship exists between cardiac output and oxygen consumption ranging from 200 to 400 cc. per minute. Training favors higher consumption of oxygen, according to some observers who believe that declining utilization of oxygen indicates that the subject is reaching the limit of his capacity for work. An increased coefficient of oxygen utilization during work is considered a mark of the trained state and is attributed to better vasomotor regulation, which permits less blood to pass through inactive tissue. Other investigators, however, believe that the minute volume for a given consumption of oxygen is higher in the trained subject than in the untrained. It is thought (8) that the increase in volume produced by exercise in the untrained is due almost entirely to the increase in heart rate.

As a result of studies in which persons were trained to perform successively heavier work on a bicycle ergometer, Christensen (8) found a new adjustment of heart rate and stroke volume at each level. If, after these reached a consistent value for a given load, the subject again returned to a lighter load, there was acceleration of pulse and a larger stroke volume than when this task was performed before. Working with an "overload" adjusted the heart to perform more economically at the lower level than training at this level, no matter how long continued.

Investigation by the United States Public Health Service on fatigue and hours of service of interstate truck drivers (27) did not reveal any very definite objective signs of occupational ill health as a result of long hours of driving, although the incidence of poor eyesight, bloodshot eyes, high white-blood-cell counts, and tremor of the hands was higher than is usually observed in healthy men of like age groups.

As a result of experiments on dogs, Broun (8) concluded that strenuous exercise causes temporary destruction of red corpuscles. Steinhaus (8) suggested that an attempt be made to determine whether, with proper food, light, and other conditions, exercise can stimulate the production of essential corpuscle "stuff" or whether it merely hastens a turn-over process in which the material of red corpuscles more quickly becomes available for the manufacture of new ones.

FATIGUE AND ACCIDENTS

It is estimated that beginning with October 1, 1941, 1,600,000 "green" workers were employed in the defense industries of the United States, which

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may mean an increase in industrial accidents, as untrained workers are more prone to suffer accidents than are the trained. During 1940, with an increase of 2 or 3 percent in total employment (6 percent in manufacturing) the increase in deaths from occupational accidents was 10 percent. However, in many industrial operations the accident-frequency rate during the 18 months preceding 1941 was double the percentage increase in employment. In three defense industries that have expanded enormously during the past year - machine-tool, aircraft-production, and shipbuilding - the number of disabling injuries per million hours worked increased 22 percent. The manufacture of explosives continues to be perhaps the most dangerous occupation; a 32-percent increase in hours worked was accompanied by a 297-percent increase in the number of disabling injuries. Other industries have had similar but less-wide excursions of accident incidence. All these figures are simply a reexpression of past experience - that industrial injury rates follow more or less closely the curves of employment and business activity (28). This abnormal increase is attributed to the following (29):

1. Employment of many new workers and reemployment of long-idle workers unfamiliar with the hazards of plant operations.

2. Lack of instruction in safe working practices and lack of systematic and sustained safety programs in plant operations.

3. Greatly accelerated pace of production.

4. Overcrowded condition of plants due to sudden and abnormal increase in working forces.

Wage loss, medical expense, and the overhead cost of insurance totaled approximately $700,000,000 in 1940 (30). Classification according to the American Standards Association cause code by the National Safety Council (30) revealed that 35 percent of 1,000 permanent disabilities and deaths were due to lack of knowledge and skill and 48 percent to improper attitude. During 1940 disabling injuries caused the loss of 25,192,000 man-days. Of the 35,000 nonfatal injuries reported in a typical industrial State, approximately 15 percent were suffered by skilled, 45 percent by semi-skilled, and 40 percent by unskilled workers. If the 1,500,000,000 man-hours lost through accidents in the United States during 1940 had been applied to the production of various implements of war, they would have built 15,000 to 18,000 large bombers, 30,000 medium bombers, 75,000 to 90,000 fighter planes, 112,500 to 225,000 trainer planes (depending on type), 450 submarines, or 45 battleships (29).

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As stated in the section on "Physiological Basis for Fatigue," when muscular work is carried too far fatigue sets in and may result in total incapacity for further effort. Although total incapacity from fatigue probably is seldom experienced in industry, less severe effects often result in reduced efficiency and proneness to accidents. In this connection it is interesting to note from the figures quoted that about three times as many accidents occur among the semiskilled and unskilled workers as among the skilled.

Accident proneness may be temporary or permanent. Temporary proneness to accident may be due to lack of skill or to fatigue. Lack of skill produces "learner accident proneness" which is comparable to "learner fatigue." New employees naturally are liable to accidents until they have formed the necessary motor habits required by their work. The employees who continue to have accidents after their learning period is completed are considered prone to accidents. These employees essentially are neurotic or psychopathic and react abnormally to life generally (3). Learner accident proneness can be reduced to a large extent by proper instruction. The permanent condition can be treated only on individual lines as a specific problem for industrial doctors. Vernon (4) says that fatigue, if considerable, is known to increase greatly the risk of accidents and quotes striking incidents in industry, especially during the World War, to substantiate his statement. For example, at a fuse factory employing about 10,000 workers the workday at first was 12 hours (75 hours a week) but later was reduced to 10 hours (58-1/2 to 64-1/2 hours a week). During the 12-hour-day period the women workers experienced 2.73 times as many accidents as they did when working 10 hours. The men, who felt the fatigue of the long hours much less than the women, experienced accidents 1.14 times more frequently. Knight (31) calls attention to the interesting fact that a reduction in hours of work leads to a decrease in the accident rate as well as in the total number of accidents.

FATIGUE AND EFFICIENCY

According to Amar (32) the whole science of human labor is condensed in the following four laws, and the whole art of work and of physical education resides in their application:

1. The expenditure of energy is in proportion to the effort of contraction, to its duration, and to the degree of contraction. - The meaning of this first law is obvious. The energy expended, or the fatigue produced, increases if the efforts are more intense and more protracted; but it must be added that this fatigue, all other conditions being equal, is doubled if the shortening of the muscles is twice as great.

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If it is on occasion necessary to exert great muscular force, it must be remembered that the latter increases less and less rapidly as the muscle approaches the limits of its contraction. The effort of contraction should not be carried to its limit, or there will be waste of energy. Violent exertions constitute abnormal conditions of muscular activity, whose consequences are irreparable.

2. The expenditure of energy required to perform a given amount of work diminishes in proportion as the rapidity of the muscular contractions increases. - But this is true only within certain limits of speed, beyond which nervous exhaustion will ensue, together with profound physiological disturbances. A rapid gait or a rapid rate of work is permissible only when it does not overload the organs of circulation and respiration. Under such conditions speed is really economical. Modern industry, which demands the qualities of skill and speed far more than strength, should confine itself to these economical speeds, of which the Taylor system suspected the existence, although it could not state what they were.

3. There is a most favorable effort and a most favorable speed for the performance of the maximum of work with the minimum of fatigue. - This is a consequence of the preceding law, and the determination of this effort and this speed constitutes the real object of the scientific organization of human energy. Whether the most delicate kind of work or the heaviest labor is in question, the force exerted and the pace of the work should always be duly proportioned, the sole guide being the data obtained by experiment.

4. Law of rest: A muscle returns more speedily to its condition of repose in proportion as its work has been more rapidly performed. - This law, formulated in 1910, is entirely comparable to the law of cooling of heated bodies. The temperature of a body which has been heated falls at a rate proportional to the temperature to which it has been raised (Newton). Similarly, the consumption of oxygen, which expresses the expenditure of energy, decreases progressively from the termination of work until the condition of repose is regained, and this decrease proceeds rapidly, the return to the initial condition occurring quickly when the work has been strenuous - of course within certain limits. The law of this decrease enables us to

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> determine the interval of rest which is necessary on each occasion to restore the physiological conditions which obtained at the outset and to divide the work into reasonable shifts. In this way a large daily output will be obtained without impairing the resistance of the organism. In the same way the degree of ventilation progressively decreases; it should resume the value normal to periods of repose 4 minutes after the work, whatever it may be, is ended.

A study of fatigue in relation to working capacity in an 8-hour plant compared with a 10-hour plant was reported by the United States Public Health Service (33) in 1920 (the investigations were made in 1917-18). These plants were huge establishments prominent in the metal-working industry. They used essentially the same machinery and processes, although the immediate product was not the same in the two establishments at the time of the investigation. The 10-hour plant was engaged largely in making munitions; the 8-hour plant had not yet begun the war work to which its immense resources were turned later. Most of the processes studied intensively at the 10-hour plant were those for making brass fuses for 3-inch shells. The operations studied at the 8-hour plant were those characteristic of the manufacture of automobiles. Briefly, the main conclusions of this study were:

> It appears to be established that industrial accidents are due to a complex of causes in which speed of production and fatigue are determining factors.
>
> (a) In the absence of fatigue accidents vary directly with speed of production, owing to increased exposure to risk.
>
> (b) The breaking up of this regular variation by fatigue is indicated by -
>
> (1) The rise of accidents with the fall of output.
> (2) The disproportionate rise of accidents with the rise of output, and the absence of a proportionate fall of accidents with the fall of output in the final hours of the day.
>
> (c) The importance of fatigue in the causation of accidents is emphasized by the fact that a higher accident risk accompanies the deeper decline of working capacity -

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(1) In the second spell as compared with the first.
(2) In muscular work as compared with dexterous and machine work.
(3) At the 10-hour plant as compared with the 8-hour plant.

(d) The level of the accident rate varies inversely with the experience of the workers.

In the absence of fatigue accidents vary in the main with speed of production. They may vary at the same rate with speed, when the curves will be parallel, or at a more rapid rate, when the accident curve will be of the same general form as the output curve but steeper. This variation is illustrated roughly in certain types of work by the rise of accidents with rising output in the earlier hours of the day. During these hours the increase of injuries is to a considerable extent automatically determined by the added number of motions with attendant exposure to danger or by the generally increased risk inherent in high-speed machinery. Similarly, with lower speed the automatic reduction of motion and attendant danger will reduce accidents at the end of each spell and preserve the parallelism of the curves. Variation of accidents with output, though at a more rapid rate, was most closely approximated in both spells at the 8-hour plant, where fatigue was only slightly indicated, and at the 10-hour plant in the first 4 hours of machine work, the type of activity showing least evidence of fatigue. In both instances the variation of accidents with output was roughly 4:1; that is, accidents varied four times as fast as output.

That variation of accidents with increase or decrease of output was not a mere mechanical result of varying speed was shown by the inconstant rate of variation. Both in dexterous work and to a less degree in machine work at the 10-hour plant the rise of accidents was disproportionate to the rise of output. Other factors besides speed of production caused this increase. Among these, loss of coordination, the readjustment of rhythm to changing speeds, may have played some part. Prominent among these factors appeared to be fatigue, to which the accident curve is said to respond more sensitively and more quickly than does the output curve. According to this hypothesis fatigue is registered first not in less work but in impaired quality of work, in errors, and in increasing inaccuracy. Even while output is still rising the onset of fatigue may be indicated by a disproportionately great increase of accidents.

In all hours of falling output except the final hours of the spells accidents continued to rise with the fall of output. Even at the 8-hour plant,

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where the variation of accidents with output in most hours was almost parallel, a fractional decline of output from the sixth to the seventh hour was accompanied by a 6-point rise of accidents. In this striking disparity the influence of fatigue in the causation of accidents was seen in conspicuous contrast to that of speed of production.

During the final hours of the day accidents should fall with the greater fall of output. In the absence of fatigue this decline of accidents should be proportionate to the decline of output, owing to lessened exposure. The counterinfluence of fatigue, however, changed this ratio. By tending to increase accidents it checked their automatic decline. So much greater, therefore, was the fall of output than the fall of accidents that accident risk still ascended.

The factor of inexperience in the causation of accidents is discussed by the Public Health Service investigators as follows:

> From the point of view of safety it is evident that beginners are undesirable employees. When a plant is undergoing expansion and labor recruiting is active a rise of accidents disproportionate to the increase of the total labor force must be expected, since in all labor recruiting there is certain to be a large proportion of inexperienced workers. Thus, in the year from December 1, 1916, to December 1, 1917, the 10-hour plant, in order to increase its force by 2,215, hired 15,619 new men and rehired 7,082. For every permanent increase about seven times as many new men were hired plus about three times as many rehired workers.
>
> Inexperience and its accompanying high accident hazard are inevitable at times of expansion and doubtless beyond a certain point irreducible. But the enormous chronic amount of inexperience shown by the high proportion of new workers and the steady inflation of the accident rate by its presence are not inevitable. This is a grave aspect of the high turnover and should prove a potent stimulus to its reduction. The menace of inexperience to a factory's safety cannot be rightly estimated by the accident rate of inexperience alone; this rate must be studied in connection with the turnover. It is obvious that the import of such an accident rate as 111.3 per 1,000 new workers quoted above (6 months' employment or less) will differ greatly according to whether 1,000 or 15,000 such new workers were employed in the course of a year. Only when the heavy hazard of inexperience is related to the number of employees yearly subject to it can we estimate its full menace in a given factory.

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The potential productive capacity of modern industry is determined by the speed at which its machines can manufacture articles, which in turn depends upon the intensity and speed at which human beings can work. A gradual revolution in industry termed "rationalization" is in process. Rationalization has been defined as methods of technique of organization designed to attain the minimum waste of effort and material. One form of industrial waste may be the unused productive capacity of machines whenever they stand idle from whatever cause (3). The more efficient use of potential capacity of machines has been accompanied by general increase in the speed at which machines operate during working hours and by the introduction of a shift or relay system. The economic gains have been considerable, and the productive capacity of the individual worker has risen enormously. The primary object of rationalization - to effect the minimum waste of effort and material - is necessary and good. However, people have begun to wonder whether its manifest advantages are not being purchased at the expense of certain "hidden costs" or wastages. Collier (3) states that if medical science could show that beyond a certain point rationalization results in increased sickness and if that point could be determined doctors would be in a position to make an extremely valuable contribution to modern industry. At present the facts do not warrant a decisive judgment, although in certain instances there seems to be reason for calling a halt on health grounds alone.

Collier (3) states that a categorical answer cannot be given to the question "What is the optimum number of hours of work?" However, he gives the following general conclusions that apparently are justified:

1. Evidence which has accumulated over a large number of years and in a variety of occupations shows that, if hours of work habitually or for long periods exceed 48 hours per 6-day week, industrial health and efficiency are bound to suffer. There is no medical evidence, however, that 48 hours constitutes the physiological optimum. The available evidence appears to suggest that, for most industrial processes, 40 or 44 hours per week are optimal and that continuous employment for 53 hours and over per week are quite definitely inimical both to health and efficiency.

2. There is evidence that, whenever a 5-day week of 44 hours is a practical possibility and is not accompanied by excessive speed of work, health and well-being are improved.

3. It appears to be certain that there is a limit to the degree by which reductions in hours of work can be attained merely by an increase of the speed of work during the shorter period.

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4. That in seeking to assess the health effects either of the number of hours actually worked or of a proposed alteration in the hours worked, the period of employment, the time of work, the speed of work, and the effects of all of these conditions upon the nonindustrial life of the worker need to be considered.

Within limitations, reduction in hours of work results in such an increase in hourly output that daily output increases. In a large factory where the weekly hours at first were 74-1/2, then 63-1/2, and later 55-1/2 the Health of Munitions Workers Committee (31) found that after each reduction in hours production increased. In the operation of turning aluminum fuse bodies (on capstan lathes) the output of nearly 100 experienced women was recorded. When nominal hours were reduced from 74-1/2 to 63-1/2 actual hours fell from 66 to 54.4, but since the hourly output increased 21 percent the total output remained unchanged. When nominal hours were further reduced to 55-1/2 (and actual hours fell to 47.5) the hourly output increased 29 percent. Hence, the total output was 13 percent greater than it had been at first, although the actual working period was now 18-1/2 hours less. These results are shown more clearly in the following table:

"Nominal" hours scheduled	"Actual" hours worked	Index of hourly output	Weekly output	Index of weekly output
74.5	66.0	100	66 x 100 = 6600	100
63.5	54.4	121	54.4 x 121 = 6582	100
55.3	47.5	157	47.5 x 157 = 7458	113

Similar results were obtained from a study of a large group of men engaged in sizing fuse bodies. Although nominal hours were reduced first from 66.7 to 60.2 and then from 60.2 to 55.5, improved timekeeping and increased speed of production resulted in a total output during the 55.5-hour week that exceeded the original output by 19 percent.

Knight (31) calls attention to the curious fact that output adapts itself more quickly when hours are increased than when they are reduced, which indicates that overtime may be uneconomical. In an American munitions plant when 2-2/3 hours overtime was added to the normal 10-hour day the hourly output dropped 6.5 percent. According to Knight (31), the following general conclusions seem to be justified by the available evidence in regard to length of working day:

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1. Every reduction in the working day leads to a decrease in accidents, spoiled work, sickness, and absence.

2. The reduction of working hours from 12 to 10 leads to an increase in hourly and daily output.

3. The reduction of working hours from 10 to 8 leads to a further increase in hourly and daily output, except in operations whose speed depends mainly on the speed of machines.

4. The reduction of working hours below 8, though increasing hourly output, does not usually lead to an increase in daily output.

Another method of judging the influence of fatigue on efficiency apparently is by the effect of rest pauses on the output of workers. Although it is important that rest between one working day and the next should be sufficient to dissipate fatigue, rest pauses during the working hours are equally important (31). During long spells of work rest is taken whether authorized or not, and even the most martial discipline cannot eliminate or suppress the effects of fatigue. However, it has been found that rest periods sanctioned by the management have a far greater recuperative effect than those taken surreptitiously by the workers. Also, the value of involuntary rest due to break-downs or inadequate supplies is apparently only about one-fifth as valuable in relieving fatigue as voluntary rest.

The following interesting instance of the effect of rest pauses during working hours is given in the report of the Committee on Work in Industry of the National Research Council (10):

Professor Mayo, a member of the Committee, pointed out the close relation between the extra-time allowances - for differences in skill and effort, for unavoidable delays, for personal needs, and for fatigue - and the human factor in industry. He naturally cited the experience of the Western Electric Co. In the bank wiring observation room there was no way of determining which delays were beyond the control of the operators, and the operators were reporting more unavoidable delays than in fact occurred. He cited also his experience in a textile mill in Philadelphia. The decision was taken to experiment with rest periods in a department of spinning mules, the mules to be shut down completely for the time of the rests. The mules worked at a standard speed and could not be speeded up. Nevertheless, in spite of the periods of shut-down, production was actually

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kept up, and in 1 month, when the workers were made to stop work for 40 minutes a day, in four periods, and lie down and rest, production was 10 percent greater during the month. Only one mule had a card showing the number of revolutions it had made. During this month records were kept of the revolutions made by this mule, and the discovery was made that whereas, when the department had been operating on an all-day basis in the month before, this machine had been worked approximately 6-1/2 hours out of the 10-hour day; now, when the 40 minutes of rest periods had been put in, the same mule worked about 7-3/4 hours out of the 10-hour day.

Again, in another industrial situation, an experiment was made in which six 5-minute rest periods were introduced in an 8-hour day. The personal time-out was reduced to a minimum. When the original conditions were restored, without rest periods, production was better, but personal time-out went back to its old figure.

Again, a foreman asked that rest periods be introduced in a particularly difficult operation. Investigations showed that the employees scouted the idea. They said: "We do all our work in the morning and ease off in the afternoon." The men were operating machines which used current, and it was possible to test their statements by measuring the amount of current they were using. The current used in the morning was far more than in the afternoon, although apparently, even in the eyes of the foreman, they worked just as hard in the afternoon as ever.

The lesson of these cases is that fatigue, personal needs, even so-called unavoidable delays, cannot be isolated as separate factors in the time required to perform a task. Each one is in a state of mutual dependence with the others, and with further factors in the conditions of work. An increase in the amount of time allowed for fatigue will produce a decrease in the amount of time taken for delays, and so on. In England, investigators in the field of industry were gradually forced to the conclusion that, while there was no fact left undescribed in the account they were giving of the way in which work was done, there was no factor which could definitely be termed "fatigue" and allowed for as such. If factors other than fatigue were sufficiently accounted for, there was no need to introduce the factor of fatigue. The Industrial Fatigue Board has now changed its name and is called the Industrial Health Board.

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If, as indicated by Mayo's statement, fatigue is not the factor concerned in the efficiency of workers under varying hours of work, what is the factor or reason underlying the benefits of shorter working periods? This question does not seem to have been answered satisfactorily, if at all, and might be a profitable subject for research.

It is interesting to note that the order of the German Minister of Work of December 12, 1939, reestablished to a certain extent the regulations governing hours of work that ceased to be applied at the beginning of the war (34). For males over 18 years of age these hours remain fixed in principle at 8 but may be extended to 10 and even 12 hours. However, when the work period is 12 hours rest intervals totaling at least 2 hours must be enforced.

Great Britain (35) also relaxed labor standards at the beginning of the war and by May 1940 British war industries were working 12 hours a day 7 days a week. Production increased for a short time, but within 2 months absenteeism became general owing in part to exhaustion of the workers. The Minister of Supply (35) concluded:

> Neither in the interests of the workers themselves nor in the interests of maximum output could a week of 7 days be worked indefinitely.

In his speech to the House of Commons on July 29, 1941, Prime Minister Churchill (35) said:

> If we are to win this war ***it will be largely by staying power. For that purpose there must be 1 day in 7 for rest as a general rule, and there must be 1 week's holiday a year.

Under section 161 of the New York State Labor Law the Board of Standards and Appeals may grant variations permitting the employment of men for 7 days a week if it finds that practical difficulties are involved in the application of the provision requiring 1 day of rest in 7 for male workers over 18. Requests made by employers for such variations within recent months indicate no widespread demand for relaxation of this form of limitation or abandonment of the principle of 1 day's rest in 7 (35). One should remember that although the average work week is shorter in the United States than abroad the tempo of American production is faster and results of fatigue would be expected to appear sooner. Every effort should be made to avoid the mistakes made abroad.

In connection with the promulgation of maximum hours-of-service regulations for interstate truck drivers the Interstate Commerce Commission asked the United States Public Health Service to cooperate in a study

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of the causes and effects of driver fatigue. The year devoted to the study was too short, and the report issued in 1941 (27) in many respects is a pioneer effort and substantially the first in which commercial drivers have been tested in their day-to-day environment. The results indicate that if fatigue is defined as an altered psychophysiological pattern the type and degree of fatigue produced by truck driving, up to quite long hours, was most strikingly revealed by changes in the relatively simple motor functions measured by four performance tests. The results of the investigation are summarized as follows:

1. Eight hundred and eighty-nine truck drivers engaged in interstate commerce were examined in a total of 1,200 sessions at field stations set up in 3 cities. Each man was given a medical examination and as many as possible of 22 special physiological and psychological tests.

2. The medical examinations showed that the drivers as a group were in good health. However, the incidence of poor eyesight, bloodshot eyes, high white-cell counts, and tremor of the hands was higher than is usually found in healthy men of like age groups.

3. The men who had not driven at all had the highest average efficiency, those who had driven less than 10 hours had the next highest average efficiency, and those who had driven over 10 hours had the lowest average efficiency on tests of the following seven functions: Speed of tapping, reaction-coordination time, simple reaction time, manual steadiness, body sway, driving vigilance, and the ability to distinguish flicker. These tests showed the most consistent and definite results from the standpoint of distinguishing between groups of men on the basis of their recent driving experience. The first four are all relatively simple performance tests which can be administered in a few minutes with easily portable equipment.

4. Men who had driven at all performed less efficiently, on the average, than those who had not driven, on tests of the following three functions: Aiming, resistance to glare, and speed of eye movement. The data from the three cities are inconsistent on the question as to whether the 10-hours-and-over group of drivers performed less efficiently than the 1-up-to-10-hours group on these tests.

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5. The average heart rate decreased slightly with hours of driving. The average white-cell count was higher in men who had driven than in men who had not driven since sleep. Among the men examined in one city the average white-cell count increased with hours of driving.

6. No trends with hours of driving were found in the estimation of size of known objects, the differential white-cell counts, the hemoglobin content of blood, the acidity of urine, the specific gravity of urine, the visual acuity, and the total base and potassium concentration of blood serum.

7. Considerable differences were shown by almost all of the tests between men examined in Baltimore, Nashville, and Chicago.

8. A method of making a composite score from a battery of tests was devised for comparing the general psychophysiological status or fatigue pattern of different individuals. Coefficients of scoring were computed by this method using the results of a battery of four tests, which included speed of tapping, manual steadiness, simple reaction time, and reaction-coordination time. Finer divisions of the data were possible and smoother curves were obtained than with any single test. This method is recommended as a means of classifying the general status of individuals when a battery of tests of different functions is administered. By this composite scoring method a progressive decrease in general efficiency was found with increasing hours of driving.

Coefficients of scoring were also calculated for a smaller group of drivers from a battery of four performance tests. The results again showed a decreased functional efficiency with increasing hours of driving.

Similarly, composite scores were calculated from 13 tests including all functions which showed changes with hours of driving. The results substantiated the above findings.

9. A detailed analysis of data from all the tests, in general, confirmed the results shown by the coefficients of scoring and none offered contradictory evidence. It appears that a reasonable limitation of hours of service of interstate truck drivers would reduce the number of drivers on the road with low functional efficiency. This, it might reasonably be inferred, would act in the interest of highway safety.

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The following statement by Schneider (24) summarizes briefly some of the important factors in fatigue:

> Fatigue, as Haggard has so well put it, is the product of two factors: One is the work done; the other is the man's susceptibility to fatigue. Susceptibility is a factor that varies from man to man and in each individual from day to day. It is determined by four factors: The individual's constitution, his habits of muscular use, the environment under which he works, and the nature of his task. A man's constitution may vary; it may be weakened by disease and strengthened by the adoption of good habits of living. For a given task he may have formed habits that use more movements and keep his muscles under a greater tone than are demanded by the nature of the work. Rhythm is a fundamental property of the nervous system; therefore we find that the building up of a series of rhythmic reflexes, which contain no unnecessary movements, is a potent factor in preventing fatigue. Unfavorable environmental factors include poor ventilation and excessive temperature and humidity. The nature of the task is an important factor. It may provide a variety of movements, or it may use few muscles over and over again. Skilled labor is more fatiguing than unskilled. Speeds of work above that which gives maximum efficiency and above the natural rhythm of the worker are unfavorable.

DETECTION OF INDUSTRIAL FATIGUE

There are scores of methods and tests for determining fatigue factors in a plant or industry. One of the simplest ways to learn whether the ill health, proneness to accident, and loss of efficiency of an individual are due to fatigue incident to his occupation is to examine the group in which he works. Although individuals react differently to occupational environment, certain common factors provide the necessary data for group diagnosis. These are occupational mortality and morbidity rates, accident and work-efficiency rates, short-time or casual absence rates, and labor turnover rates. Collier (3) states that the fundamental fact that industrial efficiency and industrial health go hand in hand is not always clearly recognized in industry, although the evidence to support this fact is so clear as to admit no doubt. Some of the signs and symptoms (3) of work inefficiency are: (a) Output rates for the group as a whole; (b) "spoiled-work" rates (which measure quality of work) for the group as a whole; and (c) "waste-material" rates or the "making of scrap" for the group as a whole.

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Another important indication of some adverse group factors (physical or psychological) is labor turnover. Owing to the costs, which include not only those due to increased accidents but also to huge losses in productive labor, turnover is a highly urgent problem in industry. That labor turnover is largely a result of conditions of work, such as long hours, low wages, and unsatisfactory environmental conditions, was revealed by studies of the Public Health Service (33) in the 8-hour and 10-hour plants. The turnover in the 10-hour plant was almost six times as high as at the 8-hour plant. The physical factors most distasteful to the men at the 10-hour plant as indicated by turnover above the average were:

	Percent
Departments with night work, turnover averaging	15.8
Departments with muscular strain, turnover averaging	14.9
Departments with bad light conditions, turnover averaging	14.6
Departments with bad air conditions, turnover averaging	13.8

PREVENTION OF INDUSTRIAL FATIGUE

Experience in individual plants in industry shows that conditions causing or contributing to fatigue of whatever type and its sequelae of ill health, proneness to accident, and inefficiency can be corrected by the application of proper measures. For example, the industrial accident rates of companies reporting to the National Safety Council (30) were almost unchanged in 1940; the frequency rate was the same, the severity rate dropped 1 percent, and the fatality rate was down 2-1/2 percent. These figures are in sharp contrast with the national totals of 10 percent increase in occupational deaths, with an increase in employment of only 2 or 3 percent, indicating a net increase in the fatality rate of 7 or 8 percent. This divergence can be interpreted as evidence that broad, fundamental safety programs made it possible for these companies to take employment increases in stride.

Accident-prevention data analyzed by the United States Department of Labor in 1929 (13) reveals the following achievements for certain large groups of industries: The power-press industry effected a 33-percent reduction in accidents in 1 year; the chemical industries, 60-percent in 4 years; paper mills, 40-percent in 7 years; the Portland Cement Association, 49-percent in 8 years; and the iron and steel industries, 56-percent in 17 years.

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As a result of the experience of the medical department of the Westinghouse Electric & Manufacturing Co., Robb (36) concluded that to eliminate accidents is not enough; the real profit comes in keeping workers healthy. Occupational diseases not only are compensable in many States, but the worker is a liability to the company from the beginning of such illness. At the Westinghouse plant the health and safety program is aimed at eliminating accidents and occupational diseases. If effective, such a program is broader in scope than merely prevention of accidents. During the last 3 years in this plant the cost of the program was increased 20 percent, while compensation costs were reduced materially each year until in 1939 they were 60 percent lower than in 1938 (36).

Another example of the results achieved by the industries in controlling environmental conditions to which workers are exposed is that of the St. Joseph Lead Co. as reported by Fletcher (37) to the Air Hygiene Foundation in 1939, which will bear repeating:

> Twenty years ago, before there were many laws covering industrial hygiene, the St. Joseph Lead Co. realized that, in order to prevent its best men from entering possibly more attractive fields, it was necessary to have the best possible living and working conditions, so that a man could satisfactorily raise his family by sending his children to good schools and maintaining his and their health. From the following, in which the cost of labor turnover is estimated, it can readily be appreciated that we were not solely influenced by any legal, paternalistic, or altruistic angle, but actually by a practical money-making viewpoint.
>
> In 1918 our labor turnover was 250 percent per year; in other words, it was necessary to employ 250 new men each year to keep 100 on the job. Therefore, to maintain our organization of some 2,500 men, we had to hire 6,250 men per year.
>
> Based on an estimated direct cost of $20 to $25 to replace one man in 1919, the direct cost of 1919 labor turnover was $125,000 to $150,000 per year, which is the minimum figure, as it is difficult to estimate the indirect costs, such as additional supervision, increased accident hazard, decreased efficiency among older employees because of the necessity of giving attention to new employees, etc., but it is probably safe to say that the indirect equaled the direct cost; therefore the total cost of the labor turnover was $250,000 per year. I might add that under present-day conditions, where machinery

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and brainwork is necessary, instead of costing about $21 per man, the figure is nearer $100.

By 1926 labor turnover had been reduced from 250 percent to 40 percent per year, and by 1933 to 4 percent. Last year it was 3.6 percent - just compare this figure with the condition existing 20 years ago.

Data collected by the Committee on Healthful Working Conditions of the National Association of Manufacturers (38) revealed that reduction in accidents was the benefit most frequently derived from health and safety programs in the industries surveyed. Of 1,388 companies reporting the effect of their programs on accident frequency, 97 percent indicated a reduction; the average reduction in 626 companies that estimated reductions was 44.9 percent. The greatest improvement reported after the introduction of health programs was in occupational diseases. An average reduction of 62.8 percent was noted in 172 companies; 92 percent of 806 companies reported reduction but did not give the amount. The number of companies estimating specific reductions and the percentage reductions reported were:

	Number of replies	Average reduction reported, percent
Compensation insurance premium.....	454	28.8%
Absenteeism.....	234	29.7 %
Labor turnover	186	27.3%

Another probably more effective but much more difficult method of preventing fatigue in industry is the physical training of the civilian population. This would provide the physical fitness so desirable not only for the individual worker and industry but for military purposes as well.

The question of providing enough manpower for military and industrial purposes is much broader than providing safe and healthy places to work. The source of industrial as well as military personnel is the civilian population. That the physical fitness of this source is much below standard is indicated by the fact that about half of the men of the American Expeditionary Force were unfit and without adequate training for any trade or profession. In spite of this deplorable condition very little has been done to remedy it since that time, and about the same, if not greater, unfitness has been found in the present-day draft selectees.

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A method of assuring physical fitness in civilian population is suggested by the experience of South African investigators in training recruits who were substandard physically and mentally. The value to themselves as well as to the Nation of physical training of young people in the civilian population is apparent from the results of this experiment (39). In 1933 a special battalion was established in South Africa to combat the deteriorating influence of unemployment and to provide discipline and training for unemployed European boys and young men who were in a low state of physical fitness. From 1933 to 1939, 13,815 boys were recruited for the training; 10,735 completed the course, and 9,409 of them later were given employment. These boys, who were between the ages of 16 and 21, had been unable to find employment. They made a dull and undisciplined impression; their posture was lax and their general bearing bad. None of the boys had received physical training in school, and their physical efficiency was virtually nil. The recruits found the training very strenuous at first, and most of them would have given up had they not been under military rule. After the first month, however, their attitude changed; they liked the exercise and cooperated willingly. The investigators stated that the significance of physical education has never before been assessed from the point of view of public health or economy, and they believe that the attainment of clearly defined standards of physical efficiency similar to the intellectual standards now required must be demanded in future. As indicated in the following statement (40), they recommend that physical training be made compulsory:

> We are aware that some of the conclusions which we have drawn from the results of our experimental survey imply interference with what may be regarded by some people as "personal freedom." However, that interference with personal freedom which we recommend, that element of compulsion which we feel our duty to demand, appears to us a fundamental necessity in the interest of the community as a whole and of the individuals constituting that community. We clearly foresee that "reasonable compulsion" will in the society of the future have to be introduced, unless the society is prepared to give up its free existence. In the past the unwillingness of the intellectual classes, of the representatives of science and of learning, to consider compulsion has been one of the most profound mistakes which in their effects have proved to be catastrophic; as catastrophic as the adoption of the principle of compulsion without reason which we have recently seen introduced in so many parts of the world.

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SUMMARY

1. Data on fatigue and health show clearly the connection between fatigue and loss of working efficiency and increased accident occurrence, but there is little actual medical proof that long, fatiguing periods of work permanently affect efficiency, health, or working capacity.

2. So many physical and psychological factors are interrelated with the whole subject of fatigue that a simple, direct definition is impossible. Perhaps from the physiological standpoint the definition of fatigue as "the sum of the results of activity which show themselves in diminished capacity for work" is fairly satisfactory.

3. The essential physical manifestation of fatigue is diminished capacity for continuing the fatiguing task. In its extreme manifestations it is indistinguishable from exhaustion and is accompanied by complete inability to continue to perform the task.

4. The essential psychological manifestation of fatigue is an increasing disinclination to continue working, accompanied by certain more or less typical "feeling states."

5. The causes of fatigue may be physical or psychological. Apparently psychological and environmental factors are far more important causes of fatigue than physiological factors.

6. Two types of fatigue are mentioned in the literature - one originating entirely within the central nervous system, the other arising partly in the nervous system and partly within the active muscles. The former is of common occurrence, whereas the latter occurs infrequently. Industrial fatigue usually is of the first type. Environmental conditions and relations with management and fellow workers are more important factors in fatigue than physical activity, except in the "heavy" industries that require hard physical labor.

7. The physical manifestations of fatigue include ill health, proneness to accident, and inefficiency at work.

8. The connection between fatigue and health is indicated by statistics on the occurrence of illness among workers of different types. Morbidity and mortality statistics show that certain diseases occur more frequently in certain industries in which fatigue apparently is the main factor. The making of munitions and other industrial work required in wartime resulted in greatly increased death rates for tuberculosis in England during the World War of 1914-18.

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Death rates by occupation collected in the United States by the National Tuberculosis Association revealed the following rates per 100,000 for males from all causes: Agricultural workers, 623; clerical workers, 775; skilled industrial workers, 829; semiskilled industrial workers, 1,009; and unskilled labor, 1,448. An excess of accidents is said to account for only 1/16 of the total excess death rate of industrial workers, whereas an excess of pneumonia is nearly twice as important and an excess of tuberculosis nearly three times as important.

9. Accidents in industries of the United States cause a loss of approximately 1,500,000,000 man-hours of production each year. If the statement is true that illness causes 15 to 20 times as many cases of absenteeism and about 7 times as much loss of time from work as accidents, the seriousness of the health problem in industry is apparent. As ill health is a frequent cause of accidents, the health program in industry would seem at least as important as the safety program that has been stressed so strongly in recent years.

10. Physical fatigue may be temporary, subacute, or chronic. Temporary fatigue is a normal feeling of tiredness that passes away after a short rest and allows resumption of the original work without decrease in efficiency. Subacute fatigue may result from continued activity at the same intensity until energy reserves are depleted. This is a short-term condition but, if allowed to continue unchecked, ultimately will develop into a chronic condition. Chronic fatigue is the final stage of the series of events of which overwork is the first and is the beginning of a condition that may result in disabling illness.

11. Fatigue may be local or general. Local fatigue affects particularly the muscles that have been employed most actively. General fatigue affects the whole body and frequently results from conditions of work, such as excessive hours, curtailed periods of rest, and insanitary, uncomfortable, or hazardous surroundings.

12. Muscular work or work under high temperature produces fatigue of peripheral physiological functions, such as metabolism, circulation, and respiration. In easy muscular work fatigue originates exclusively in the central nervous system.

13. There is a physiological basis for fatigue. Experiments on persons reveal that if the interval of rest between muscular contractions and the weight of the load lifted are kept constant the contractions decrease in extent with fatigue until with the strongest voluntary effort contraction is insufficient to lift the weight. The fact that fatigued muscle relaxes more and more until it is completely nonirritable has led to the definition of fatigue as "more or less complete loss of irritability and contractility due to functional activity."

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14. Chemical changes in muscle during contraction form certain substances that depress or inhibit the power of contraction. These fatigue substances consist of the known products of muscular metabolism.

15. Some authorities doubt whether there is any evidence that the muscles can be injured directly by overwork under normal conditions as they are protected by the sense of fatigue which makes voluntary use of muscle more and more difficult.

16. Fatigue probably develops in the motor end plate and the nerve centers more quickly than in the muscle, protecting the muscle from an extreme condition of fatigue. Although strain usually is not carried far enough to injure the muscle itself beyond possibility of restoration, occupational neuroses indicate that the nerve centers may be damaged and that other mechanisms, such as the heart and blood vessels, may be affected injuriously, particularly if there are any abnormalities in structure or function.

17. The manner in which muscular contraction is brought about is still a matter of speculation. An adequate theory of muscle contraction should explain the mechanism that produces shortening of the contractile elements, the nature of the energy that is transformed into mechanical work, and the relation of these phenomena to the chemical changes that follow stimulation of the muscle to activity.

18. Excessive, violent exercise quickly causes a rise of lactic-acid content of muscle to the maximum of about 0.28 percent, muscle being incapable of further effort when it contains this amount of free acid. When a fatigued muscle is placed in oxygen the lactic acid will decrease to resting value and the muscle regains its irritability.

19. The rate at which the body consumes oxygen during exercise varies almost directly with the amount of external work performed. A man's maximum working power is determined not only by the functional capacity of his skeletal muscles but also by the supply of oxygen to the muscles, heart, and brain. The supply of oxygen is the limiting factor. The total consumption of oxygen during exercise is roughly proportional to the mass of active muscles.

20. A delicate adjustment between the activity of the skeletal muscles and that of the medullary centers is required to maintain adequate blood pressure for the nutritive requirements of the heart and brain and to make the necessary correlation between the venous inflow and the pulse rate required to keep up the mechanical efficiency of the heart and the body as a whole. The controlling influence of the higher centers is apparent at

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every stage of exercise. A man's nervous organization is as important as the size of his muscles, and his muscular development is by no means the only criterion of his capacity for muscular exertion.

21. Strenuous physical work or sport may lead to enlargement of the heart. The size of the heart of an animal reflects the extent of activity characteristic of its mode of life.

22. Physical training reduces the pulse rate. At rest the trained or athletic subject has a higher minute volume than the untrained. Training favors higher utilization of oxygen and correspondingly lower minute volume for a given optimum consumption. Declining utilization of oxygen indicates that the capacity for work is being exhausted.

23. There is a new adjustment of heart rate and stroke volume at each level in persons trained to perform successively heavier tasks. Working with an "overload" adjusts the heart to perform more economically at a lower level than training at this level, no matter how long continued.

24. Increase in employment in the defense industries of the United States may mean an increase in industrial accidents and illness, as untrained workers are more likely to suffer accidents and occupational diseases than are the trained. During 1940, with an increase of 2 or 3 percent in total employment, the increase in deaths from occupational accidents was 10 percent, although in some industries the rate was the same or even less. In the machine-tool, aircraft-production, and shipbuilding industries the number of disabling injuries per million hours worked increased 22 percent. In the manufacture of explosives a 32-percent increase in hours worked was accompanied by a 297-percent increase in number of disabling injuries.

25. The reasons for this abnormal increase are employment of new workers or reemployment of workers long idle and unfamiliar with the hazards of plant operation; lack of instruction in safe working practices and lack of systematic, sustained safety programs in plant operations; greatly accelerated pace of production; and overcrowded condition of plants due to sudden and abnormal increase in working forces.

26. During 1940 disabling injuries caused the loss of 25,192,000 man-days. The total loss in production by accidents was about 1,500,000,000 man-hours.

27. Fatigue may be accompanied by some increase in the risk of accidents. During a 12-hour-day period women workers experienced 2.73 and men workers 1.14 times as many accidents as they did later during a 10-hour-day period.

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28. Investigations by the Public Health Service indicate that industrial accidents are due to a complex of causes in which speed of production and fatigue are determining factors.

29. Investigations by the Public Health Service emphasize the factor of inexperience as a cause of accidents. In the 10-hour plant investigation during the year December 1, 1916, to December 1, 1917, 15,619 new employees were hired and 7,082 were rehired to increase the force by 2,215. The accident rate during this period was 113.3 per 1,000 new workers who had been employed for 6 months or less. As inexperienced and unskilled workers are more easily fatigued than experienced and skilled workers it may be assumed that at least part of this susceptibility to accidents was due to fatigue.

30. The "rationalization" now in process in industry, which is designed to attain the minimum waste of effort and materials, may include "hidden costs" as a result of increased fatigue, sickness, and accident proneness of workers in trying to keep pace with the speed at which the machines operate during working hours.

31. The question "What is the optimum number of hours of work?" has not been answered satisfactorily. However, the evidence available indicates that industrial health and efficiency suffer if hours of work exceed 48 per 6-day week. Whenever a 5-day week of 44 hours is a practical possibility and is not accompanied by excessive speed of work health and well-being are improved.

32. In seeking to assess the health effects of the number of hours actually worked or of a proposed alteration in the hours worked, the period of employment, the time of work, the speed of work, and the effects of these conditions upon the nonindustrial life of the worker should be considered.

33. The influence of fatigue on efficiency may be judged by the effect of rest pauses on the output of workers. In some plants production was 10 percent greater during the month when workers were made to stop work for four 10-minute periods during the working day.

34. Investigation of fatigue of truck drivers by the Public Health Service revealed that men who had not driven at all had the highest average efficiency, those who had driven less than 10 hours had the next highest, and those who had driven more than 10 hours had the lowest average efficiency in tests of speed of tapping, reaction-coordination time, simple reaction time, manual steadiness, body sway, driving vigilance, and the ability to distinguish flicker. Men who had driven at all performed less efficiently, on the average, than those who had not

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driven in all tests of aiming, resistance to glare, and speed of eye movement. Using a composite scoring method, a progressive decrease in general efficiency was found with increased hours of driving. The conclusion reached from these tests was that a reasonable limitation in hours of service of interstate truck drivers would reduce the number of drivers on the road with low functional efficiency. This, it might reasonably be inferred, would react in the interest of highway safety.

35. A simple method of determining whether ill health, accident proneness and loss of efficiency of an individual are due to fatigue incident to occupation is to examine the group in which he works. If the occupational mortality and morbidity rates, accident and work-efficiency rates, short-time or casual absence rates, and labor turnover rates are high in the group, it may be inferred that the symptoms exhibited by the individual are due to his occupation. Output and spoiled-work and waste-material rates for the group as a whole are indications that the conditions of work may be producing undue fatigue, which reveals itself in loss of working efficiency and increase in accidents.

36. The conclusion of the Committee on Work in Industry of the National Research Council regarding fatigue apparently is that, although certain conditions in various kinds of work make it necessary for men to play or rest - and it would be misleading to assume that some of the different states that are called fatigue do not exist in industry - they are much less common than is generally supposed. The committee points out that in some instances at least the sensation of fatigue is related to the total situation of the individual rather than to the specific operation he has to perform.

37. Experience in individual plants and industries shows that conditions contributing to fatigue and its sequelae of ill health, accident proneness, and inefficiency can be corrected by applying proper measures.

38. A solution of the problem of providing enough manpower for industrial and military purposes has been suggested by an experiment in South Africa in physical training of unemployed boys and young men between the ages of 16 and 21 who were in a low state of physical fitness and unable to find employment. The results of this experiment led to the recommendation by the investigators that physical training be made compulsory and that in the future clearly defined standards of physical efficiency similar to the intellectual standards be required.

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